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Renewable energy management in a remote area using Modified Gravitational Search Algorithm

Sahand Ghavidel

Shiraz University of Technology

Jamshid Aghaei

Shiraz University of Technology, jamshid@uow.edu.au

Kashem M. Muttaqi

University of Wollongong, kashem@uow.edu.au

Alireza Heidari

University of New South Wales

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Abstract

In this paper, a small remote area which is located in Nigeria has been considered as a model to be tested by a managing scheme for providing both electricity and water. In this strategy, the groundwater is pumped into a water tank which can be later used for supplying required irrigation and drinking water. A PAT (Pump as Turbine) is used as a hybrid system for supplying electricity and water as well as storing water in the water tank. Also, a PV (photovoltaic plant), a package of batteries (BAT) in addition to a diesel ICE (internal combustion engine) are used and optimized along with the best size of devices and managing system, with the purpose of obtaining the maximum economical operating strategy. In this paper, two cases are considered to assess the effectiveness of the system under study. Firstly, all of the mentioned devices are used to show how internal combustion engine system dominates all the other components due to the low cost of fuel. In the second case, all renewable resources have been exploited and optimized in order to make a 100% renewable system with least possible cost. Having about 53 variables makes this problem very complicated which requires to be solved by an algorithm with more accuracy. Therefore, a MGSA (Modified Gravitational Search Algorithm) with an adapted mutation tactic is used to find the best cost and management strategy. In the first case, although the cost of diesel oil is very low, by using the PAT, about 5% of diesel oil consumption is reduced. In the second case, in order to make a 100% renewable system, the size of PV is enlarged approximately 16 times in comparison with the first case. The hybrid PV-PAT storing structure is capable to deliver the water for irrigation and domestic requirements as well as 9% of the electricity needed for the rural community.

Keywords

search, algorithm, management, remote, renewable, area, energy, modified, gravitational

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Renewable Energy Management in a Remote Area using Modified Gravitational Search Algorithm

SAHAND GHAVIDEL¹, JAMSHID AGHAEI¹, KASHEM M. MUTTAQI², ALIREZA HEIDARI³

¹Department of Electronics and Electrical Engineering, Shiraz University of
Technology, Shiraz, Iran

²Australian Power Quality and Reliability Centre, SECTE, University of Wollongong,
Wollongong, Wollongong, NSW, Australia

³School of Electrical Engineering and Telecommunications, the University of New
South Wales, NSW, Sydney, Australia

Abstract- In this paper, a small remote area which is located in Nigeria has been considered as a model to be tested by a managing scheme for providing both electricity and water. In this strategy, the groundwater is pumped into a water tank which can be later used for supplying required irrigation and drinking water. A Pump as Turbine (PAT) is used as a hybrid system for supplying electricity and water as well as storing water in the water tank. Also, a photovoltaic plant (PV), a package of batteries (BAT) in addition to a diesel internal combustion engine (ICE) are used and optimized along with the best size of devices and managing system, with the purpose of obtaining the maximum economical operating strategy. In this paper, two cases are considered to assess the effectiveness of the system under study. Firstly, all of the mentioned devices are used to show how internal combustion engine system dominates all the other components due to the low cost of fuel. In the second case, all renewable resources have been exploited and optimized in order to make a 100% renewable system with least possible cost. Having about 53 variables makes this problem very complicated

which requires to be solved by an algorithm with more accuracy. Therefore, a Modified Gravitational Search Algorithm (MGSA) with an adapted mutation tactic is used to find the best cost and management strategy. In the first case, although the cost of diesel oil is very low, by using the PAT, about 5% of diesel oil consumption is reduced. In the second case, in order to make a 100% renewable system, the size of PV is enlarged approximately 16 times in comparison with the first case. The hybrid PV-PAT storing structure is capable to deliver the water for irrigation and domestic requirements as well as 9% of the electricity needed for the rural community.

Keywords: Gravitational Search Algorithm, Modified techniques, Photovoltaic pumping systems, Pump as turbine, Energy storage

Nomenclature:

$F_{best}(t)$	best fitness from all achieved results for each agent	ε	constant value
$F_{worst}(t)$	worst fitness from the results for each agent	$a_i(t)$	the accelartion for each agent
n	number of variables	$v_i^{(t)}$	velocity of each agent for each iteration
$M_i(t)$	mass designed for each agent	$x_i^{(t)}$	position of each agent for each iteration
$f_i(t)$	the fitness function for each agent	$R_{ij}(t)$	Euclidean space among agent i and agent j
$rand_j()$	random number	G	Gravitational constant
X_{ji}^k	i^{th} member of each agent in the iteration k for the current existing agent j	M^k	mean value of the population
$X_{j,trial}^k$	i^{th} member of each agent in the iteration k for the trial agent j	A_{res}	capacity of reservoir

θ	learning degree	A_{PAT}	capacity of BAT
K_{max}	the determined number of iterations	c_{Fuel}	price of fuel in € per Liter
ww	weight factor	m_h	fuel mass flow rate
$NPOP$	the maximum number of agents	Δt	time interval
c_{PV}	price of PV in € per m ²	P_{users}	load demand
c_{ICE}	price of ICE in € per kW	P_{PV}	generated power
c_{BAT}	price of BAT in € per kWh	P_{ICE}	power of ICE
c_{res}	price of reservoir in € per m ³	P_{BAT}	power of BAT
c_{PAT}	price of PAT in € per kW	P_{PAT}	power of PAT
S_{PV}	capacity of PV	V	tank volume
S_{ICE}	capacity of ICE	Q_{tank}	amount of flow rate of the reservoir
S_{BAT}	capacity of BAT	Q_{users}	water suitable for drinking required for rural community
$F(X_j)$	main objective function and the constraints	Q_{irr}	amount of water required for irrigation
$f(X_j)$	main objective function	Q_{PAT}	amount of flow rate related to the PAT system
λ_z	penalty factor of the constraint violation z	$VIOL_z$	value of the constraint violation z repository

1

2

1. Introduction

These days, the act of making remote areas profitable of renewable sources is a possibility due to a favorable combination of circumstances which can gives many people having opportunity to gain access to electricity and water. For the areas that the electricity network are not obtainable for usage, the stand-alone photovoltaic pumping systems can be used for supplying electricity in addition to required irrigation and drinkable water. Also, the environmental issues, energy saving and using lower amount of fossil resources with higher efficiency has to be considered more than ever. In addition, there are some difficulties in remote areas such as right of way and transmission line expansion. However, the usage of local resources in particular the renewable ones, can give the people living in remote areas, an opportunity to gain access to electricity with more reliability.

The reliable access to both irrigation and drinking water is also very important to people living in these remote areas. Recent years, many strategies have been suggested about coordinating pumping systems with local renewable sources such as Ref. [1] which investigated the coordination of supplying required water with local renewable energy resources in the inner area of Nigeria. Ghoneim in [2] found diesel engines very cheap, if well designed, while Ref. [3] discovered them not suitable in Algeria from economical point of view. Khelif et al. in [4] proposes a PV-diesel engine system by analyzing the fuel cost, while Ref. [5] analyzes the greenhouse effect of the similar system. Ngan and Tan in [6] also added a set of wind turbines to a similar arrangement of elements.

Using hydrogen storage has been carefully practiced and designed in Ref. [7].
González et al. in [8], having the requisite qualities for normal growth and development
of hydrogen production in accompaniment with wind power have been analyzed.
Beccali et al in [9] have computed different sites of hydrogen production in the matter of
their costs and dependence on wind energy. Ref. [9] tries to optimize a large-wind-
hydrogen strategy with regards to the sizes of these devices, and a wind-PV strategy is
introduced and optimized in Ref. [10].

Another important storage system is Compressed Air Energy Storage (CAES) which
makes available a lot of added supports [11] and it can be used either as a sustenance
[12] or in a combined heat and power system [13]. Safaei and Keith in [14] analyzed
different benefits of this solution including economic and environmental issues. Kim and
Lee in [15] studied CAES as a storage part in a new hybrid system integrating with
pumped hydro plants which are a new joined together technology. These new
technologies are frequently used as a sustenance for wind energy systems [16].

According to the good performance and life cycle of small solar supported heat
driven chillers, the use of these technologies have been extended to such structures with
a common compression chiller supported by a PV. For example, Beccali et al. in [17]
intended to deliver a widespread study of these solar supported cooling systems (using
solar thermal or PV). Beccali et al. in [18] provided a more widespread study over an
assessment of these solar supported cooling systems. In the paper, two more
arrangements of these systems were studied to additionally define the PV supported
systems. Also, a performance comparison between the Italian and the Brazilian context
regarding to Eco-design of solar driven systems has been done in Ref. [19].

The water tank is also a storage system which has been used as a new storage strategy for pumped hydro power plants and can function as a supporter energy source along solar power plants [20]. Refs. [21, 22] evaluated the use of PAT in hydro power plants in the matters of the system's performance and choosing right pump for the system.

It is very demanding to make an arrangement scheme for hybrid systems due to their complex system [23]. Therefore, for solving these complex systems, a variety of techniques have been presented. Chicco and Mancarella in [24] proposed a model based on matrix optimization for tri-generation systems, and also Chicco and Mancarella in [25] reported a comprehensive review of a variety of techniques for the optimization of such systems.

Further explanations on Nigeria remote area background are provided as follows. In [1], Cloutier and Rowley are completed an economical investigation in the central areas of Nigeria with the purpose of evaluating the practicality of renewable energy resources to alternate the conventional pumping systems. Hamidat et al. in [26] subjects to an analysis with the intention of increment of the efficiency of a PV-PAT system connected to electricity local grid for different kinds of cultivated plant that is grown commercially on a large scale in Nigeria. Kaldellis et al. in [27] declares a plan for a stand-alone photovoltaic pumping system equipped with batteries for storage purposes, capable of covering irrigation and required water suitable for drinking in remote areas. Ohunakin et al. in [28] are studied and argued the present viewpoints of solar energy exploitation by means of a renewable energy choice in Nigeria as a position of supportable progress.

Gravitational Search Algorithm (GSA) is a new artificial intelligent algorithm presented in 2009 [29], and is used in different objective functions with obtaining better results than those obtained by many other algorithms such as particle swarm

optimization (PSO) and genetic algorithm (GA). Even though this algorithm is derived 1
from a simple concept, but, it has a great power in solving optimization problems. It has 2
also a little drawback regarding to trapping in local optimal positions. There are a lot of 3
modifications have been accomplished on this algorithm. In order to improve the typical 4
GSA, Han and et al. in [30] recommend a robust hybrid GSA which makes better the 5
global search as well as exploiting the sequential quadratic programming to speed up the 6
local search. Provas and Chandan in [31] outlines an effective quasi-oppositional GSA 7
to resolve short term hydrothermal arrangement problem. Also, for solving the same 8
problem as [31] in power system, Gouthamkumar et al. in [32] proposed a disruption 9
based gravitational search algorithm which utilized a successful approach to handle 10
system constraints. 11

In order to tackle the mentioned drawbacks, a new self-adaptive learning strategy is 12
used which includes two updating approaches to increase the operation of the GSA 13
algorithm. The first strategy is related to transferring data between the agents. The latter 14
strategy is used for helping the algorithm to flee from local optima. By using a 15
probability technique, each agent chooses one of these two approaches with better 16
effectiveness to acquire an enhanced condition. In this paper, proposed Modified 17
gravitational search algorithm (MGSA) applied to a hybrid system including PAT, PV, 18
BAT and ICE aimed at providing electrical energy and supplying irrigation and 19
drinkable water to a remote area in Nigeria. 20

This paper is arranged as follows. Section 2 describes a brief overview of GSA and 21
proposed MGSA. Section 3 presents the model of the hybrid system and objective 22
function, and finally Section 5 presents and discusses about the results for the hybrid 23
system under study. 24

2. Modified GSA

2. 1. Mechanisim of GSA

The GSA as a novel artificial intelligent algorithm is based on the rule that was derived from the law of gravity. This algorithm is worked by the principles of mass reciprocal action using the theory of Newtonian laws. In physics, gravitation is an inclination of objects with themselves [29, 33, 34]. A system is supposed with n masses to depict the presented method which can be seen as follows,

$$x_i = [x_i^1, x_i^2, \dots, x_i^n]. \quad (1)$$

After calculating the objective functions for all agents, the best fitness from all achieved results is called $F_{best}(t)$ and the worst fitness from the results is called $F_{worst}(t)$. After calculating the best and worst fitness, the mass designed for each agent can be easily calculated by,

$$M_i(t) = \frac{Q_i(t)}{\sum_{i=1}^n Q_i(t)}, \quad (2)$$

where $Q_i(t)$ can be calculated for each existing agent by following function,

$$Q_i(t) = \frac{f_i(t) - F_{worst}(t)}{F_{best}(t) - F_{worst}(t)} \quad (3)$$

where $f_i(t)$ is the fitness function which is also called the cost function.

Next, the accelartion for each agent must be calculated. For doing so, the total force applied on each of them is calculated by means of using Newton rules as follows,

$$F_i(t) = \sum_{j \in K_{best} \atop j \neq i} \text{rand}_j() G(t) \frac{M_j(t)M_i(t)}{R_{ij}(t) - \varepsilon} (x_j(t) - x_i(t)) \quad (4)$$

where $\text{rand}_j()$ is a number which is randomly and uniformly distributed among 0 and 1

for each agent. Also, ε is a constant value which is very slight and small. By using the

calculated total force, the accelartion for each agent can be calculated as follows using

Newton rules,

$$\begin{aligned} a_i(t) &= \frac{F_i(t)}{M_i(t)} \\ &= \sum_{j \in K_{best} \atop j \neq i} \text{rand}_1() G(t) \frac{M_j(t)M_i(t)}{R_{ij}(t) - \varepsilon} (x_j(t) - x_i(t)) \end{aligned} \quad (5)$$

The following formulas show the modified velocity and position of each agent calculated using the the accelartion:

$$v_i^{(t+1)} = \text{rand}_2() \times v_i^{(t)} + a_i(t), \quad (6)$$

$$x_i^{(t+1)} = x_i^{(t)} + v_i^{(t+1)}, \quad (7)$$

where $\text{rand}_1()$ and $\text{rand}_2()$ are numbers which are randomly and uniformly distributed

among 0 and 1 for each agent. $R_{ij}(t)$ is the Euclidean space among agent i and agent j .

K_{best} is the finest value of K agents which their value reduced by increasing the value of

iteration. As well as K , the value of Gravitational constant (G) is decreased by each

iteration which can be seen as follows,

$$G^k = G_0 \times \exp\left(\varpi \times \frac{Iter}{Iter_{max}}\right) \quad (8)$$

where G_0 and ϖ are set to 100 and 20, respectively [34].

Comparing with PSO algorithm, GSA algorithm has two privileges [29, 34]. Firstly, the act of moving in PSO is calculated only by P_{best} and G_{best} , but the act of moving in GSA is designed through all forces of other agents. Secondly, contrary to PSO algorithm, the prevailing remoteness among answers affects the new situation of each agent in GSA.

2. 2. Self-adaptive learning strategy (SALS) used for GSA

In order to increase the capability of the GSA, a novel self-adaptive learning strategy which is shortly called SALS is used and implemented to the original algorithm. To do so, two methods have been utilized, which each of them is related to different iterations by implementing in a probabilistic way. Each method utilizes a value that is probabilistic and based on the capability of the related appraising technique. In addition, in order to help each agent determine one method among the two methods which can be seen as follows, a tool which is called the Roulette Wheel Mechanism (RWM) is used.

Method 1: In the first technique, the enhanced algorithm exploited an exterior memory for obtaining the finest solution called G_{best} which obtained from solutions saved until now. EGSA can use this G_{best} for updating the solutions as follows,

$$x_{j,\text{method1}}^k = x_j^k + \text{rand} \left(G_{\text{best}}^k - LF^k M^k \right) \quad (9)$$

$$j = 1, \dots, N_1$$

where rand is the random value between 0 and 1. M^k is the mean value of the population. N_1 is the amount of agents which the technique 1 are using, and the value of LF can be either 1 or 2 [34].

Method 2: This second method is used to diverse the solutions, avoid lack of movement and being trapped in local optima. Five agents can be choosed randomly for

each agent j in the way that $m_1 \neq m_2 \neq m_3 \neq m_4 \neq m_5 \neq j$. By using these agents, a trial solution can be calculated as follows [34],

$$X_{j,\text{trial}}^k = X_{m_1}^k + \text{rand1}(X_{m_2}^k - X_{m_3}^k) + \text{rand2}(X_{m_4}^k - X_{m_5}^k), \quad j = 1, \dots, N_1 \quad (10)$$

where rand1 and rand2 are numbers which are randomly and uniformly distributed among 0 and 1 for each agent. Also, N_1 is the number of agents which the technique 2 are using. EGSA can use this method for updating the solutions as follows [34],

$$X_{j,\text{method2}}^k = \begin{cases} X_{j,\text{trial}}^k & \text{if (rand} \leq 0.5) \\ X_{ji}^k & \text{else} \end{cases} \quad (11)$$

where X_{ji}^k and $X_{j,\text{trial}}^k$ are the i^{th} member of each agent in the iteration k for the current existing and trial agent j , correspondingly. The better value is selected as a solution between $X_{j,\text{method2}}^k$ and X_j^k [34].

The probability of both mentioned approaches are calculated by [35],

$$\text{prob}_{\text{method1},2} = (1 - \theta) \text{prob}_{\text{method1},2} + \theta \frac{a_{\text{method1},2}}{k_{\text{max}}} \quad (12)$$

where θ is a learning degree in the direction of adjusting the learning quickness of the algorithm which is selected to be 0.142 [34]. K_{max} is the determined number of iterations, and $a_{\text{method1},2}$ is the accumulator which is updated individually for each strategy as follows [34, 35],

$$a_{\text{method1},2} = a_{\text{method1},2} + ww_{1,2} \quad (13)$$

where ww is a weight factor which is assigned for each agents in order to help them choose one method among two methods, and can be calculated as follows [35],

$$ww_j = \frac{\log(NPOP - j + 1)}{\log(1) + \dots + \log(NPOP)}, \quad (14)$$

$$j = 1, \dots, NPOP$$

where $NPOP$ is the maximum number of agents. In a final manner, the normalised probability values can be defined as follows,

$$\text{Prob}_{\text{method1,2}} = \frac{\text{Prob}_{\text{method1,2}}}{(\text{prob}_1 + \text{prob}_2)} \quad (15)$$

In the EGSA solution technique, one trial solution method is chosen according to the probability using RWM. Then, the chose method is subsequently used for related target solution. Fig. 1 shows the flowchart of the EGSA algorithm.

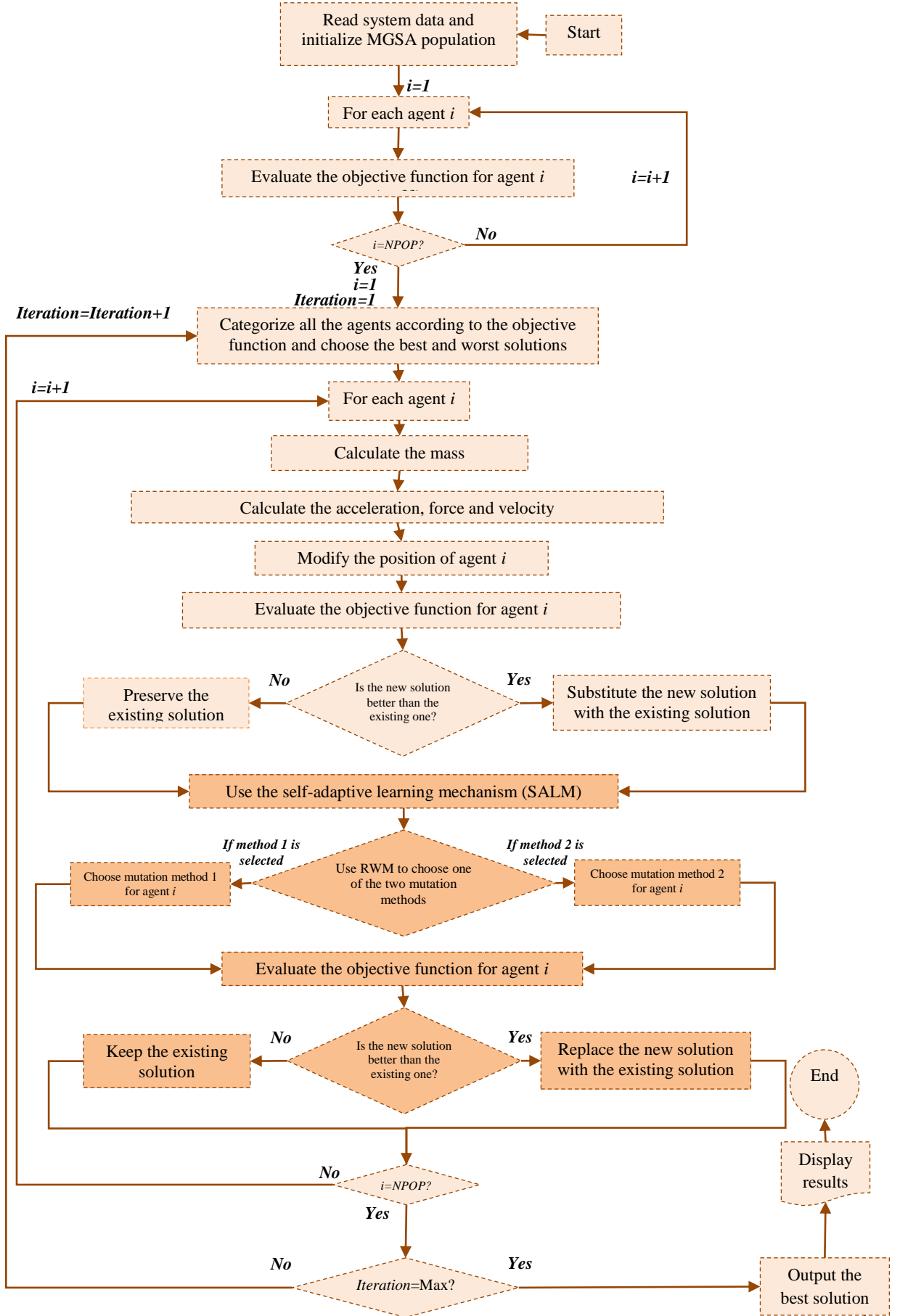


Figure 1. Flowchart of the EGSA algorithm

3. The model

Fig. 2 displays a symbolic form of the system under study which has been optimized and managed to increase the efficiency. As it can be seen from this figure, an isolated structure based on the combination of PV-pumping system is used to indicate the efficiency of the coordinated system which includes a PV, a PAT, a BAT and an ICE.

This system is aimed to provide energy for the electrical devices used by consumers including mainly radio set as well as light bulbs, and similarly supply dry land with water in addition to water suitable for drinking for about 50 families (250 persons) live on a small scale rural and isolated village in the North Nigeria [23].

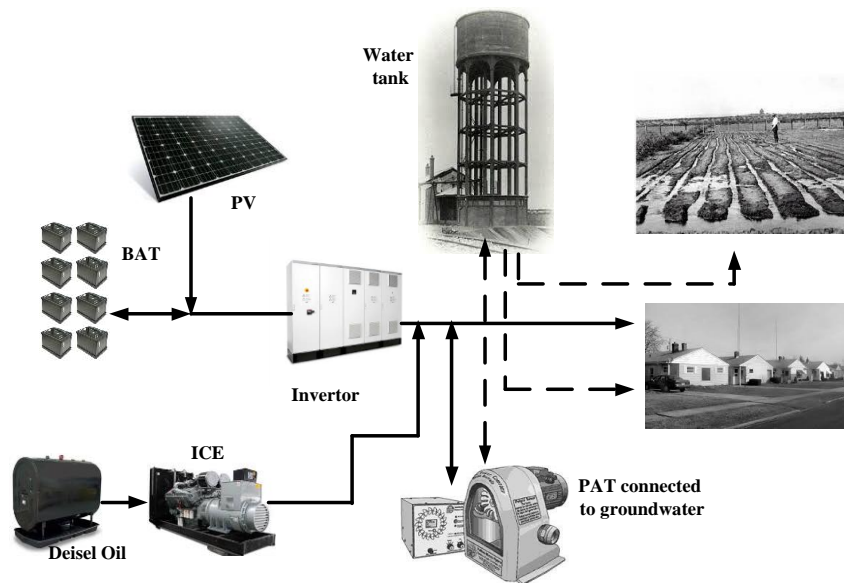


Figure 2. Diagram of the structure under study: solid lines indicate the electrical conduction and dot lines show water transmission.

The amount of electricity and water suitable for drinking which are used in the village for a given day in summer can be seen in Fig. 3 and Fig. 4 [23]. Notice that most of the electricity in the village is consumed by people in the duration of time when PV cannot produce energy. The daily supplying dry land with water for irrigation is 17 m³ [26].

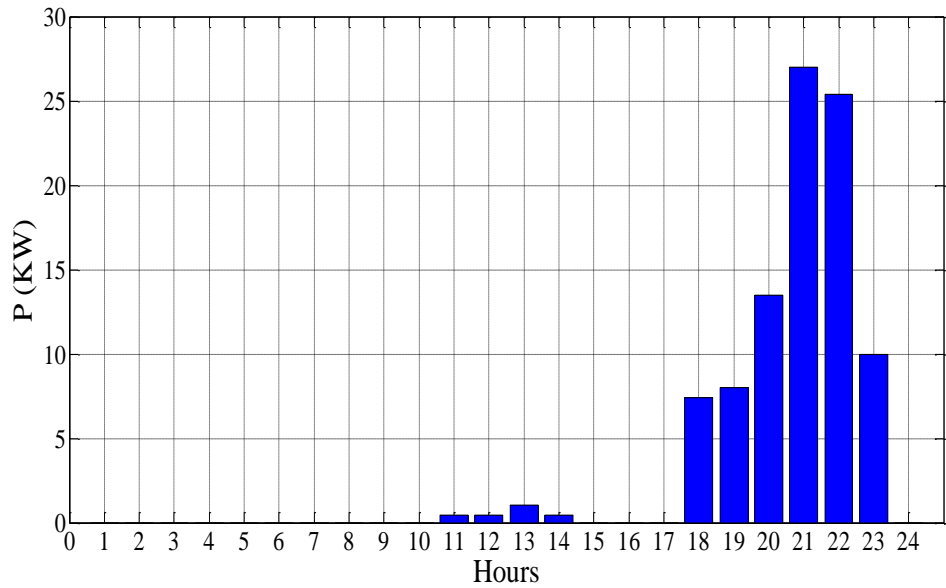


Figure 3. Hourly electricity demand.

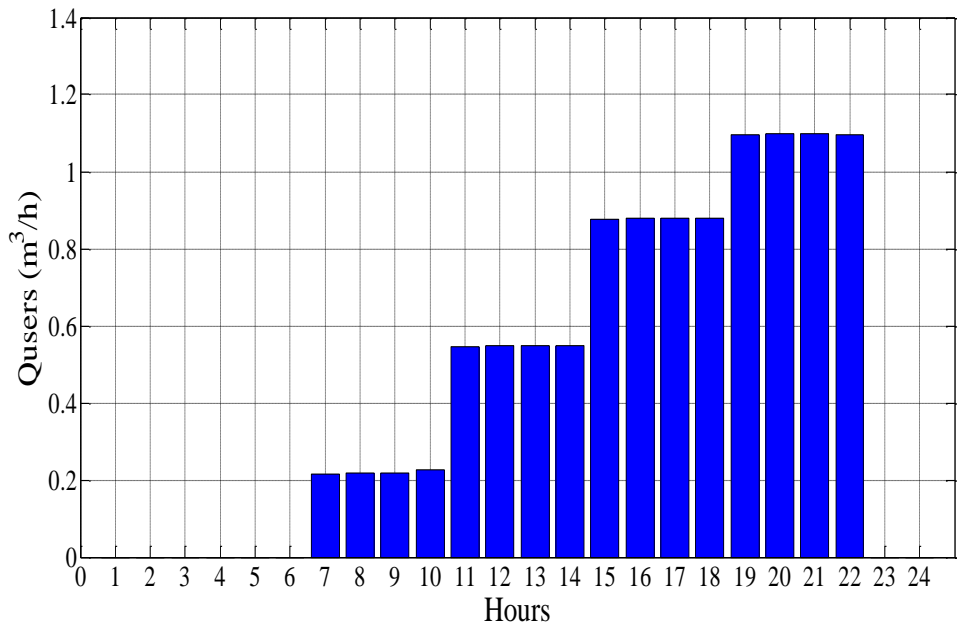


Figure 4. Hourly water demand.

Water is moved up from underground water 60 m deep, and the concrete tank provides the water storage in the pumping system. The head loss is considered in the flow rate as well as the considered pipes length [23].

The energy of pumping for water suitable for drinking and irrigation system and also the required electricity are provided with the PV and diesel engine system. The pumping system can be used as a pump to store water in the reservoir which can be used later in the turbine to supply power for users which helps to increase the efficiency of the whole system [23, 36]. The lower quantity of the volumetric flow rate is 30% and the upper amount of it is 100% of the full flow rate through pumping condition. The lower rate of the volumetric flow rate is 50% and the upper amount of it is 100% of the maximum flow rate during turbine operation mode. Also, the amount of the reservoir tank in the last hour of each day is compelled to be the same as the amount of the beginning of the day [23].

In order to increase the storage capacity and further improvement in the efficiency of the system, a BAT is provided. The lowest amount of SOC for the pack of batteries is considered to stay at 10% and the maximum quantity of allowable DOD is considered to be 90%. It is considered that a maximum determined value of discharge rate remains at 0.2 kW/kWh of maximum amount of BAT's SOC which makes the efficiency of the battery about 75%. Also, similar to the level of the reservoir, the SOC of the battery in the last hour of each day is compelled to be the same as the amount of the beginning of the day. The efficiency of the ICE system is 0.328 by having the smallest possible quantity of 30% of the load. The complete duration life of the different component of the system is different from each other. PV has the life span about 25 years. ICE, PAT and

reservoir have the life span about 10, 20, and 15 years, respectively, whereas the life span of battery is calculated by the optimization problem [23].

The information associated with hourly solar irradiance, hourly air temperature as well as hourly wind velocity have been derived from Refs [28, 37-40] which have been utilized to predict in advance the hourly electrical energy provided using the photovoltaic plant. The particular photovoltaic hourly provided electrical energy is shortened in Fig. 5 which considers the dependency of the alteration effectiveness of the PV unit temperature [41] making an allowance for a tilt angle of 15 degree. The prices of every components and the fuel can be seen in Table 1.

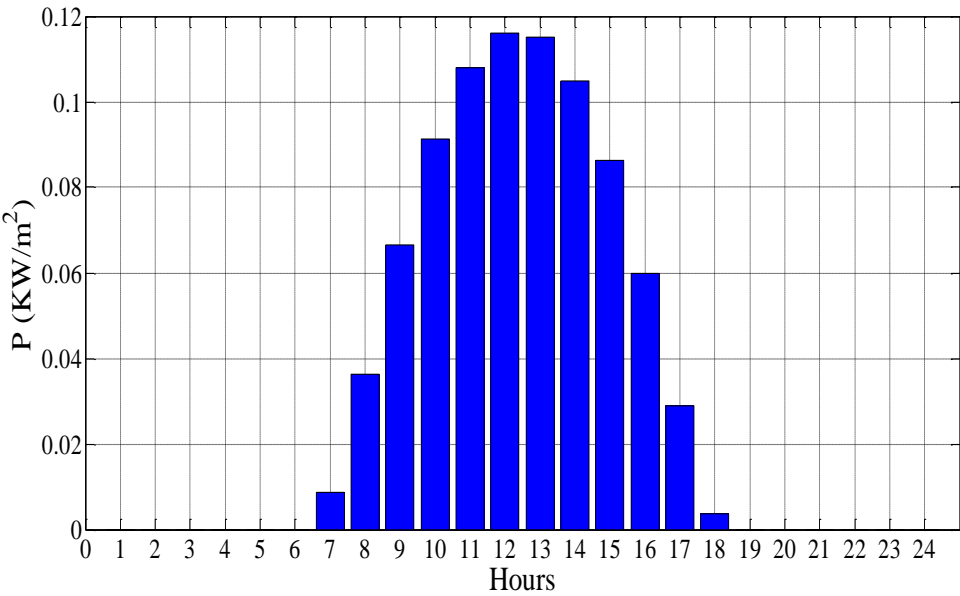


Figure 5. Hourly electrical energy provided using the photovoltaic plant.

Table 1: The prices of every components and the fuel in the system under study.

Parameters	Values
PV	340 €/m ²
ICE	1000 €/kW
BAT	210 €/kWh
Reservoir	100 €/m ³
PAT	180 €/kW
Fuel	0.66 €/Liter

The intention of this optimization procedure is to optimize the size values of the PV, ICE, PAT, and BAT as well as water tank and their operation strategy. This objective function can be expressed as [23],

$$f(X_j) = (c_{PV}S_{PV} + c_{ICE}S_{ICE} + c_{BAT}S_{BAT} + c_{res}A_{res} + c_{PAT}A_{PAT}) + \sum_{h=1}^{24} c_{Fuel}m_h\Delta t \quad (16)$$

where m_h [kg/h] is the fuel mass flow rate, and Δt is the time interval with the given amount of 1 hour. As mentioned before, c_{BAT} is evaluated by considering batteries life span. Notice that S_{ICE} is imposed to be 0, when the system is using only renewable energy. Number of variables are 53 which include 48 hourly decision variables, fuel and water mass flow rate in the pump as turbine system, and 5 devices size. The power balance constraint can be written as follow [23],

$$P_{users} = P_{PV} + P_{ICE} + P_{BAT} + P_{PAT} \quad (17)$$

where P_{users} is the load demand, P_{pv} is the PV generated power, P_{ICE} is the power of the ICE. P_{PAT} and P_{BAT} are the power of the PAT and BAT systems, respectively which can be either positive or negative.

Other important constraints are related to the value of reservoir volume and the flow rates balance which can be defined as follow [23],

$$0 \leq V \leq V_{\max} \quad (18)$$

$$Q_{\text{tank}} = Q_{users} + Q_{irr} + Q_{PAT} \quad (19)$$

where V is the tank volume (m3), Q_{tank} is the amount of flow rate of the reservoir which can be either positive or negative values, Q_{users} is the water suitable for drinking required for rural community, Q_{irr} is the amount of water required for irrigation. Also, Q_{PAT} is the amount of flow rate related to the PAT system.

It is assumed that the amount of water in the reservoir and battery charge in the last hour of each day is compelled to be the same as the amount of the beginning of the day which can be expressed as [23],

$$\begin{aligned} V_{h=24} &= V_0 \\ SOC_{h=24} &= SOC_0 \end{aligned} \quad (20)$$

Finally, the overall objective cost function and the constraints of the system can be written as the sum of the two terms including the main objective function and the constraints as follow,

$$F(X_j) = \min f(X_j) + \sum_{z=1}^{nc} \lambda_z [VIOL_z]^2 \quad (21)$$

where nc is the total quantity of system constraints, $VIOL_z$ is value of the constraint violation z and λ_z is the penalty factor which can be selected independently for each constraint.

4. Results and discussions

Case 1: exploiting renewable energy sources along ICE

Table 2 shows the best cost result calculated by MGSA algorithm which is compared to the results obtained by other techniques. Judging from Table 4, it can be seen that the minimum cost is 11939.92 €, with an average cost of 11939.93 €, and a maximum cost of 11939.93 € which are less in comparison with the other used algorithms. As it can be seen from the results, the minimum, maximum and the average cost values are very close to each other which clearly show the superiority and robustness of the proposed algorithm. Also the convergence of the algorithms for the problem with minimum cost is shown in Fig. 6. The calculated optimum devices sizes are PV=10.39 m², ICE=27 kW, PAT= 3.1 kW (as pump) with water storage volume of 23.2 m³, and BAT=15.49 kWh with life span of 1.9 years.

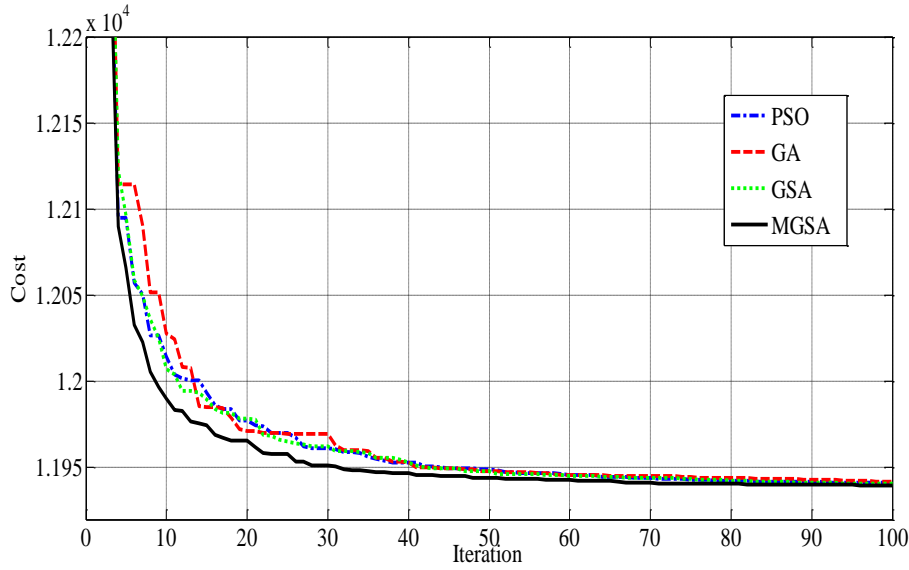
Table 2: Best cost result calculated by MGSA algorithm compared other techniques for case 1.

Algorithm	Best solution	Mean	Worst solution	Standard Deviation
GA	11941.09	11941.23	11941.37	0.07238
PSO	11941.93	11942.00	11942.09	0.03817
GSA	11940.88	11940.90	11940.93	0.01028
MGSA	11939.92	11939.93	11939.93	0.00334

Table 3: Best cost result calculated by MGSA algorithm compared other techniques for case 2.

1

Algorithm	Best solution	Mean	Worst solution	Standard Deviation
GA	24131.73	24131.84	24131.98	0.06118
PSO	24132.07	24132.13	24132.21	0.03156
GSA	24130.71	24130.72	24130.74	0.00710
MGSA	24129.50	24129.51	24129.52	0.00335



2

Figure 6. convergence of the algorithms for the problem with minimum cost for case 1.

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Fig. 7 indicates the hourly power trends of the system components including the

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pump as turbine, the photovoltaic plant, the package of batteries and the diesel internal

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combustion engine. Note that the negative values in the figure shows that the PAT

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system is working as pump, and also for battery system it shows that the BAT is

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charging. Fig. 8 and Fig 9 show the hourly trends of the BAT's SOC and the water

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reservoir, respectively. It is very important to know that by using the proposed

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management strategy, the batteries are keeping away from being charge and discharge

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many times at short intervals, which helps to increase their life span and hence reduce

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their cost.

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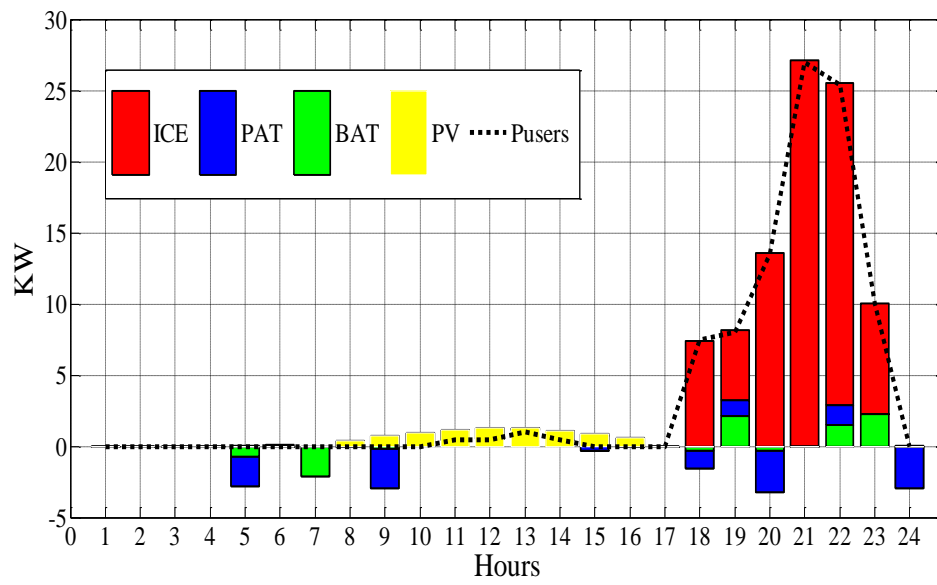


Figure 7. Hourly power trends of system components for case 1.

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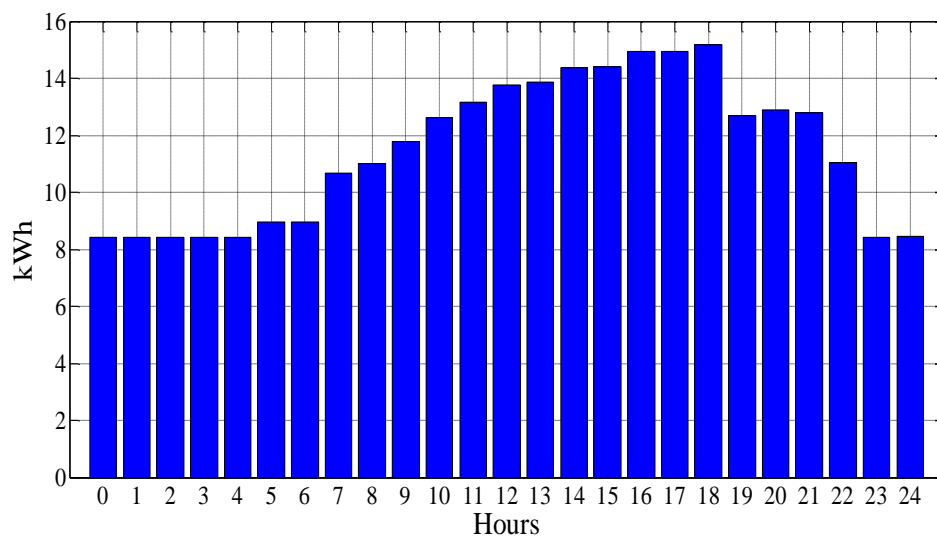


Figure 8. Hourly trends of the batteries SOC for case 1.

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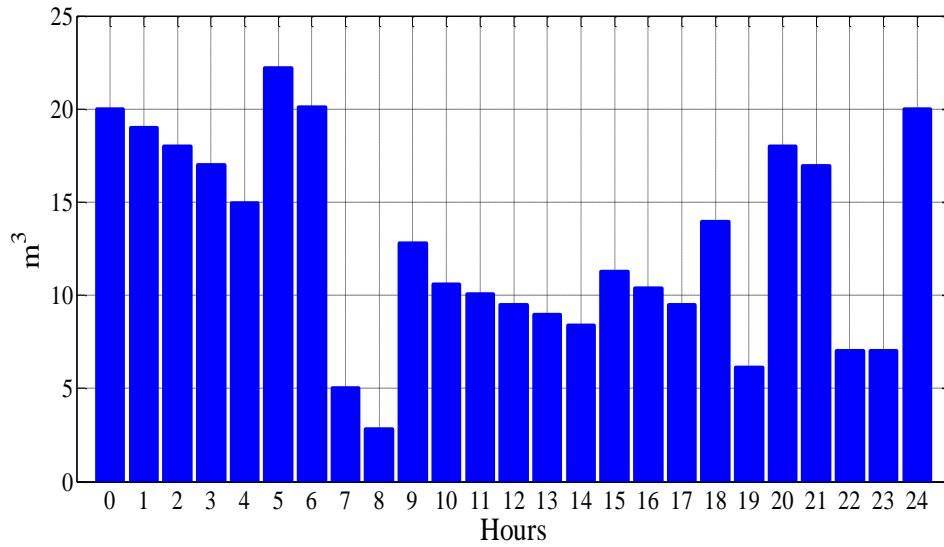


Figure 9. Hourly trends of the water tank for case 1.

Due to the low cost of the fuel, the PV and the BAT are not being operated to a great extent. Also, the size of the PAT is associated with the required water. Despite anything to the contrary, the use of the PAT and the battery allows fuel saving about 4% and 5% of energy requirement, respectively. It is arousing the attention to notice that the presence of PAT and the battery also makes certain of that the fossil fuel engine be able to operate properly and supplies about 92% of electrical energy.

Case 2: exploiting only renewable energy sources

Table 3 shows the best cost result calculated by the proposed algorithm which is also compared to the results obtained by other algorithms used in the paper. According to the Table 3, the minimum cost of 24129.51 € is calculated which are lower compared with other techniques. Fig. 10 also depicts the convergence of minimum cost of the algorithms.

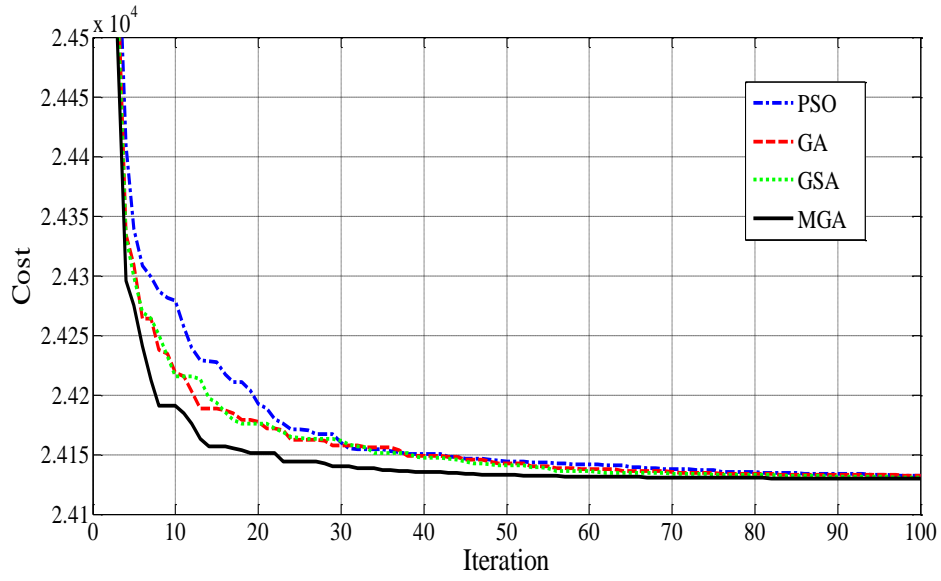


Figure 10. convergence of the algorithms for the problem with minimum cost for case 2.

By exploiting only renewable energy, the calculated optimum devices sizes are PV=166 m², BAT=131.7 kWh with life span of 1.43 years, and PAT= 13.49 kW (as pump) with water storage volume of 100 m³, which is the maximum determined water stored volume in the optimization problem. Fig. 11 shows the daily power trends of system components including the PV, ICE, BAT and PAT. Fig. 12 and Fig. 13 show the hourly trends of the batteries SOC and the water tank, respectively. As it can be seen from these figures, the PV energy is accumulated and saved until needed as 11% of water, 79% of battery, and also 10% of it is used directly by consumers. It is also interesting to notice that the exploitation of the PAT system permits the battery not to get on top of the discharge maximum rate.

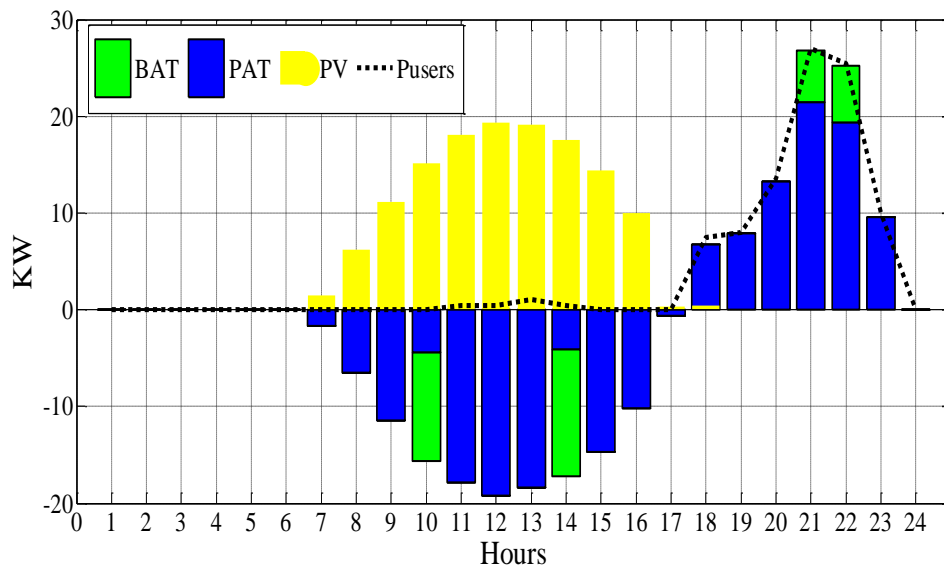


Figure 11. daily power trends of system components for case 2.

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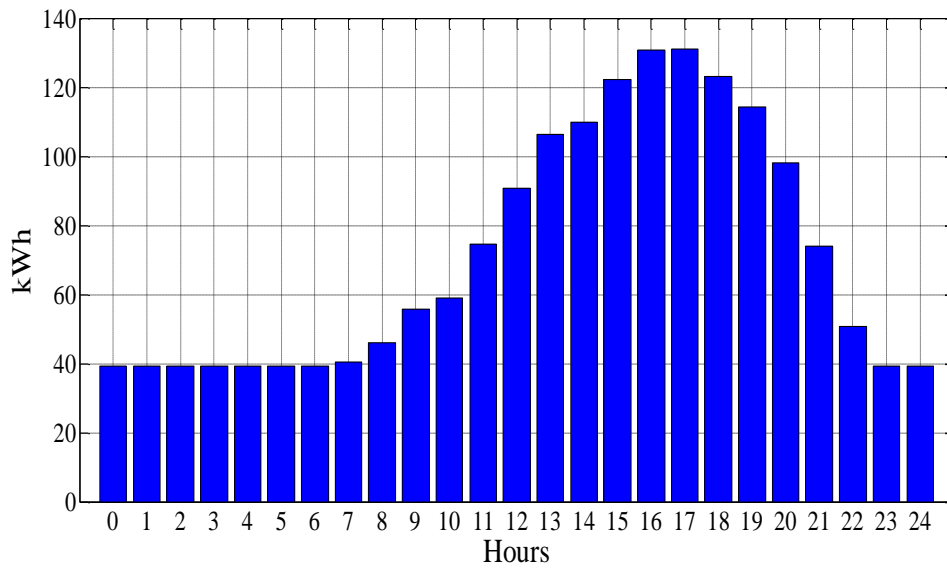


Figure 12. the hourly trends of the batteries SOC for case 2.

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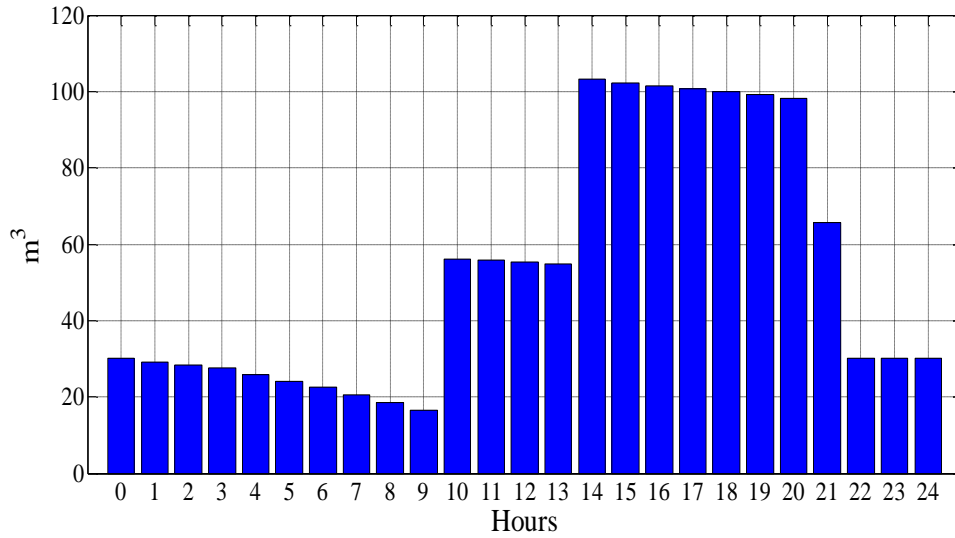


Figure 13. the hourly trends of the water tank for case 2.

5. Conclusion

In this paper, a modified GSA technique with an adapted mutation tactic is used to find the best cost and management strategy of a PV-based PAT system that is composed of a pack of batteries and a water reservoir for a remote area in Nigeria. By using the proposed strategy, the cost of the system has been optimized in two cases by considering both exploiting renewable energy sources along ICE and only exploiting renewable energy sources. In the first case, the ICE system dominates all the other components due to the low cost of fuel, whereas in the second case, all renewable resources have been exploited and optimized in order to make a 100% renewable system with least possible cost. As reported acquired results have shown, the MGSA has achieved an enhanced optimum result in comparison with other algorithms in finding the best cost and management strategy of the proposed hybrid system.

Additional expansion studies will take account of considering the stochastic behavior of PV resources as well as adding wind power resources to the hybrid system and considering the stochastic behavior of them. Also, a combined heat and power-based

distributed generation can be penetrated into the hybrid system with an optimal control
on their generation in order to supply both electricity and heat. Furthermore, the
proposed mutation strategy added to the GSA can be used and implemented to other
newly introduced optimization methods.

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